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MOBILE CONTROL CENTERS THE ADAPTABILITY OF GROUND EFFECT MACHINES AND EXISTING GROUND VEHICLES

BY

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FOREWORD

The MITRE Corporation is concerned with the survivability of the Air Force Command and Control Systems. It conducts studies in this general area in order to determine the levels at which various systems components fail and investigates various alleviating measures which may be employed to raise the levels of survivability.

One phase of this work concerns itself with the use of mobile command posts for various Air Force commands.

Although mobile command posts may in the future operate on the land, in underground tunnels, on and under the sea, in the air and in space, this study limits itself to an investigation of the use of land vehicles only. Further, the problems of operations and communications which are certainly as important as the vehicles themselves are not considered in this phase of the work.

It is the purpose of this study to determine whether the adaptation and conversion of certain existing ground effect vehicles and heavy land vehicles to mobile Air Force command posts capable of resisting all effects of a nuclear weapon at a range where the overpressure is equal to or a little below 25 psi, can be accomplished, or should effort be concentrated on designing new units especially tailored to this specific Air Force use.

This report was prepared by the Guy B. Panero Engineering Company for The MITRE Corporation.

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MITRE STUDIES RELATED TO SURVIVABILITY OF AIR FORCE COMMAND AND CONTROL SYSTEMS

SR-18, "On the Application of the Theory of Locking Media to Ground Shock Phenomena," M. G. Salvadori, R. Skalak, and P. Weidlinger.

SR-19, "Theoretical Studies on Ground Shock Phenomena," M. L. Baron, H. H. Bleich, and P. Weidlinger.

SR-22, "A Study on the Effect of a Progressing Surface Pressure on a Viscoelastic Half-Space," M. L. Baron, R. Parness, J. L. Sackman, and P. Weidlinger.

SR-26, "A Submersible Emergency Command Control Communication Barge," S. S. Murray.

SR-28, "On the Wave Transmission Between Liquid and Voight Solid," C. C. Mow.

SR-29, "MITRE Seminar on Survivability of Command Control Systems," J. J. O'Sullivan and F. R. Eldridge.

SR-30, "Design of Superhard Command Post, 10,000 psi Water Shaft Concept," Marc Peter.

SR-31, "The Adaptability of Ground Effect Machines and Existing Ground Vehicles," Guy B. Panero Engineers.

SR-33, "Design Study for a Superhard Shallow Buried Emergency Command Post," E. Cohen and G. Pecone.

SR-34, "Soft Filled Liners for Rock Tunnels in Very High Pressure Environments," Newmark, Hansen and Associates.

SR-37, "An Experimental Study of Cavity Collapse Mechanism," Lewis T. Assini, John K. Hawley, and C. C. Mow.

SR-39, "The Feasibility of a Radiation Protected Communications Repair Vehicle," T. W. Schwenke, N. J. Donnelly, W. W. Hicks, and B. A. Frances.

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I SCOPE OF WORK

A cursory look has been taken at Ground Effect Machines and Ground Vehicle development and production. The purpose of this look was to see if presently developed units could be adapted for use as Mobile Control Centers. At the same time, standard weapons effects data have been calculated and checked out as to what they mean to vehicle characteristics and to Control Center criteria. While the effects data may be repetitive with respect to previous studies by this office and others, it was necessary to get a feeling for their relation to this particular problem.

The selection of optimum criteria, adaptation methods, the function of the vehicles, optimum types of vehicles, costs for various protection levels and size ranges, consideration in detail of operating problems, vehicle configuration, materials of construction—all these items, while they may be touched upon here, are beyond the scope of this study.

II CRITERIA

A. Established for Study

A developed Ground Effects Machine (GEM) or Ground Vehicle was sought which could be adapted to:

1. Carry 8-11 operational and command personnel with command and control center facilities.
2. Withstand weapons effects of 5, 10 and 20-MT weapons if within 25-psi range.
3. Have off-road/on-road capability at speeds of 45-50 MPH and comply with highway specifications.

B. Implied by Concept

While this study does not concern itself with the operational plan for mobile control centers, certain conditions were set up to the extent that they would affect the vehicle evaluations.

1. Hardness. The basic aim was toward a vehicle with a consistent hardness, that is, equal ability to cope with overturning forces, thermal effects and nuclear radiation. Where difficulties were indicated at the 25-psi level, a lower level of 10 psi was arbitrarily investigated. An attempt was made to give credit for mobility without inflating its value. While the mobility of the vehicle affects many conditions, two important ones are:

(a) Random movement to reduce targeting possibilities and enhance chances of being exposed to low psi levels rather than high ones.

(b) Ability to move intelligently away from high residual radiation areas when attack pattern permits.

The first requires no comment. The second, depending on the interpretation, greatly affects the shielding requirements, i.e., vehicle weight and thence size, speed, environment, etc. For example, if we assume a single-weapon attack upwind with continuing mobility, the vehicle can be moved crosswind immediately following the blast to minimize residual radiation effects. In this case no shielding is necessary for up to 15-psi levels with a 5-MT weapon; up to 15-psi levels with a 10-MT weapon; and for less than 10-psi levels with a 20-MT weapon. Above these levels shielding is required for initial radiation. At high over-pressure levels it is probably unsafe to apply theoretical radiation intensities to prescribe shielding thicknesses. Thermal radiation may create temperatures sufficient to weaken structurally or even fuse rims, bearings or the like to the point that mobility is impaired and high level downwind residual radiation is experienced.

For the purpose of this study, desired attenuations for the determination of shielding weights were based on a one-week dose in the vehicle of no more than 75 roentgens total dose. This is somewhat arbitrary in that there appears to be some divergence of opinion as to effect at various doses. The intent was to prevent dosages which might, within one week after attack, cause, through nausea, etc., a reduction in command ability.

It has been considered that the Control Center has to be fully operational at all times. In other words, that you cannot have "duty suspension battle stations"--that is, areas of heavy shielding where men can ride while the Center is moving out of the high residual radiation area, with the operational area shielded to a lesser degree. Also, of course, initial radiation, where encountered, is instantaneous. No attempt has been made to vary the thickness of shielding between roof and floor, etc., to conform to variations in radiation levels. It is recognized that these may be important tradeoffs and refinements in brightening the picture as to the feasibility of mobile control centers.

The provision of an ability to resist weapons effects by the abandonment of mobility through the use of "slit trench" protection, either upon being notified of an impending attack or following the first attack, was considered and rejected. While in the first situation it would give a "pseudo" hardness capability to high psi levels and in the second situation would give fallout protection without heavy shielding, it was considered that seeking fixed protection would in both situations make it possible for the Center to be established as a fixed target and treated accordingly.

2. Size. The operating space is considered to be a control center for a Commander and three assistants plus two communications men who operate and maintain all electronic gear. The remaining personnel are two drivers. In addition there is the space required for electronics communications gear and facilities. The total volume of space required for the above is estimated to be approximately 2700 cubic feet. This with 7 feet floor to ceiling to allow for conduits results in approximately 400 square feet of inside body area. For an on-road vehicle this probably means a van with inside dimensions of something on the order of 9 feet wide and 44 feet long.

3. On-Road Capability. This means that the vehicle must have a peacetime on-road capability as well as wartime and therefore must:

(a) have dimensions which do not exceed 13 feet in height, 10 feet in width (one lane), and consist of not more than one tractor and two trailers;

(b) have a gross weight of no more than 32 tons if a single vehicle or 40 tons trailered;

(c) have operating characteristics such as control, braking, speed and acceleration comparable to that of a conventional vehicle;

(d) not have a deteriorating effect on paved surfaces and existing traffic.

III WEAPONS EFFECTS

This section deals with the effects of 5-, 10- and 20-MT nuclear weapons in the 25 and less overpressure ranges and the limitations or requirements imposed by these effects. Effects at less than 25-psi overpressures were looked at in the search for requirements low enough to make feasible an on-road vehicle. Surface bursts were used except in the case of thermal radiation. Here an air burst was used as giving the worst condition.

A. Nuclear Radiation

The fission yields of weapons were taken as given in "The Effects of Nuclear Weapons" to determine residual radiation dosages. Initial radiation yields were taken as given in the Corps of Engineers Manual #EM 1110-345-413. Three attack situations have been considered:

1. A non-mobile condition downwind from a single weapon at the overpressure ranges specified.
2. A mobile condition with a single weapon where the vehicle is subjected to the initial radiation consistent with the specified overpressures but then moves crosswind to a point 10 miles from the GZ (Ground Zero) line before the arrival of fallout at that location. The vehicle is then presumed to be subjected to the residual radiation consistent with that location for one week.
3. Countrywide fallout as plotted in Fig. 6.18 of TECHOPS Report No. TO-B 60-13 Dec. 1, 1960, was used. This plot shows percentage of U. S. Contaminated to Given Values or Less for seven different attacks, four by the

RAND Corporation and three by OCDM. The apparent mean curve was selected for all seven attacks and the radiation intensity which was approached or equalled and conversely equalled or exceeded in 50% of the area of the country was taken as the one-hour reference dose experienced by the vehicle. This dose rate was estimated at 2000 roentgens/hour. This is equal to 5800 roentgens for one week.

Table 1 shows the initial and residual radiation dosages for the respective weapons, 5, 10 and 20 megatons, for various overpressures, and the theoretical amounts of shielding required for attack situations 1 and 2. Detailed calculation tabulations are shown as Exhibit B in the Appendix. The thicknesses of shielding indicated are for attenuation of the total dose encountered over a one-week period to the level of 75 roentgens.

Reduction of the accumulated deposit of radioactive fallout by a built-in air jet or water wash of the outside of the vehicle has been considered but rejected on the grounds that:

1. The surface of the vehicle will char, pit or oblate, depending on the type of surface provided, as a result of thermal radiation and will therefore be a difficult surface to cleanse of minute particles.

2. The quantities of air or water required to do a thorough cleaning job during the fallout period exceed the quantities that could reasonably be carried by the vehicle. Outside contaminated air could be used with an outside compressor either for preset

TABLE 1

INITIAL AND RESIDUAL RADIATION DOSES DOWNWIND AND CROSSWIND FROM BLAST FOR ONE-WEEK DURATION (ATTACKS #1 AND #2, RESP'LY)

Weapon Surface Burst	Over-press	Initial Radiation Gamma (R)	Initial Radiation Neutrons (Rems)	Residual Radiation Downwind (1000 R)	Residual Radiation Crosswind (R) *	Lead Shielding Reqd. Downwind (Inches)	Lead Shielding Reqd. Crosswind (Inches)
5 MT	1	<10	<10	15.9	<10	2.1	None
	2	"	"	18.5	"	2.3	"
	3	"	"	20.6	"	2.3	"
	4	"	"	22.1	"	2.4	"
	5	"	"	22.6	"	2.5	"
	10	"	"	25.2	51	2.5	"
	15	30	"	27.3	51	2.5	"
	20	52	"	27.8	51	2.6	0.3
	25	200	85	28.3	51	2.8	2
10 MT	1	< 10	< 10	19.4	<10	2.3	None
	2	"	"	21.9	"	2.4	"
	3	"	"	23.8	"	2.5	"
	4	"	"	25.8	"	2.5	"
	5	"	"	27.1	"	2.5	"
	10	"	"	29.6	65	2.5	"
	15	20	"	32.2	65	2.6	"
	20	110	"	32.9	65	2.6	0.6
	25	340	"	33.6	65	2.7	1.5
20 MT	1	<10	<10	23.8	<10	2.5	None
	2	"	"	25.2	"	2.5	"
	3	"	"	28.4	"	2.5	"
	4	"	"	29.2	"	2.5	"
	5	33	"	31.7	81	2.6	"
	10	110	"	35.8	81	2.6	0.6
	15	500	"	37.4	81	2.6	1.8
	20	2600	"	40.0	81	3.6	3.4
	25	5200	"	40.6	81	4.2	4.0

*Based on the assumption that vehicle moves 10 miles crosswind immediately after blast.

nozzles or by personnel for short periods of time, but such an ability could not be guaranteed.

3. The "shine" from fallout on the ground cannot be avoided when moving and shielding must be provided for full protection against this radiation.

It is realized that there is a possibility of decontamination stations or areas where a vehicle can be driven in and cleaned. However, it is considered here that no credit can be given for this likelihood.

In summary, for 25-psi overpressures from a 5-MT weapon, shielding from initial radiation requires 2 inches of lead shielding; 1.5 inches for a 10-MT weapon; and 4 inches for a 20-MT weapon. A loss of mobility in the downwind 25-psi location would necessitate 2.8, 2.7 and 4.2 inches, respectively, for total radiation. The 2000-roentgens/hour reference dose on the basis of national fallout projections (residual radiation only) requires about 1-3/4 inches of lead.

A feel for the weights of shielding involved may be given as follows for complete shielding at uniform thickness for the van portion of the vehicle described under Section II, Criteria.

Two inches of lead shielding weighs approximately 100 tons.

If one discounts the national fallout picture and concedes that a lower psi rating may continue to be interesting, the shielding against initial radiation at the 10-psi range for a 20-MT weapon amounts to 0.6 inches or 60 tons of lead. For the crosswind mobility of the No. 2 type attack, the 8-psi range total radiation levels are below those requiring shielding.

B. Thermal Radiation

The effects of thermal radiation are somewhat less well defined than are those of nuclear radiation. The condition and color of the skin of the vehicle are all important. The amount and duration of the thermal radiation, which are dependent on the size of the weapon, visibility conditions, and whether there is an air burst or surface burst, are important factors as to the actual temperature rise of the outside surface of the vehicle skin.

The total thermal energy transmitted in calories per square centimeter for given overpressure levels is highest for air bursts. Table 2 shows the total thermal energy for single 5-, 10- and 20-MT weapons at the 5, 10, 15, 20 and 25-psi overpressure levels, and for a visibility of 2 to 50 miles.

Detailed calculations to determine the outside and inside vehicle temperatures for a specific complete cross-section of paint, skin, structural covering, shielding material and insulation, with the determination of the various conductivities, rates of heat transmission and the transient heating and cooling effects for each condition, have not been made in this study and are considered to be more properly calculated during the selection of a specific cross-section. There have been made, however, certain very approximate calculations to provide a feel for the thermal effects and to permit certain observations to be made.

TABLE 2

THERMAL ENERGY RECEIVED AT VARIOUS OVERPRESSURES

Air Burst Weapon	Overpressure	Thermal Energy
Megatons	(psi)	Calories per cm^2
	5	75
	10	225
5	15	650
	20	1450
	25	3000
	5	100
	10	270
10	15	840
	20	1800
	25	3500
	5	115
	10	340
20	15	1000
	20	2000
	25	3800

From: The Effects of Nuclear Weapons Handbook

These calculations assume that 40% of the total thermal energy received at the range for each overpressure level is absorbed and raises the temperature of the material it impinges upon under steady state conditions on the basis of the thickness and specific heat of the material. For these simplified calculations a 1/2-inch steel plate was assumed as the surface to receive the energy.

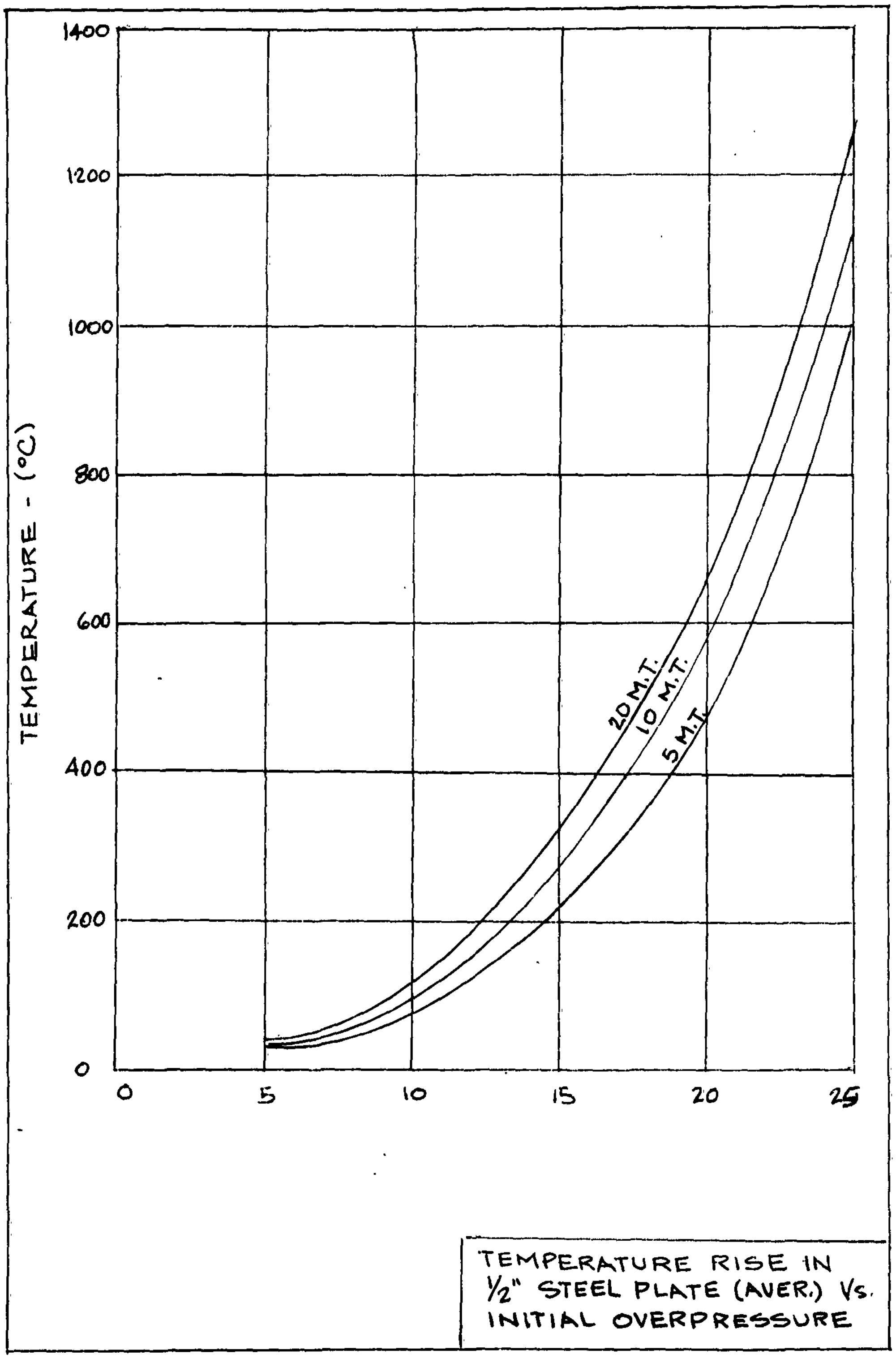
The resulting temperatures were taken as average temperatures throughout the 1/2-inch plate. Fig. 1 shows temperature curves for the 5-, 10- and 20-MT weapons as air bursts.

Mr. H. Mow of Mitre made calculations for the inside and outside surfaces for a 1-centimeter steel plate under the thermal radiation conditions at the 25-psi overpressure range of a 5-MT weapon. Forty percent (40%) of the theoretical total thermal energy was used as the input to the vehicle (60% considered to be attenuated, reflected, or conducted away).

The inside and outside temperatures were calculated to be approximately 900° and 1400° centigrade, respectively. These two figures, if averaged and adjusted for 1/2 inch of steel for comparison with the temperature of the previous approximate steady-state calculations, result in an average cross-section temperature of 905° C.

The comparable temperature by the simplified steady-state calculations is 1040° C. The variation in these two figures is approximately 15%. Calculations by RAND personnel have indicated slightly higher temperatures. It is therefore felt that the approximate temperatures of Fig. 1, being bracketed by others, are in the proper range. It is recognized that they may be high

Fig. 1


TEMPERATURE - (°C)
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
20 M.T.
10 M.T.
5 M.T.
TEMPERATURE RISE IN ½" STEEL PLATE (AVER.) Vs. INITIAL OVERPRESSURE

for high overpressure levels for the large yield weapons in view of the fact that the variation in time-duration of energy emission has been neglected.

In summary, these approximate calculations result in rises in temperature in the range of 100° C. for the 10-psi overpressure level and 1000° C. to 1300° C. for the 25-psi level. This means that the melting point of steel may be approached or exceeded at 25-psi levels. The ignition point of rubber may be exceeded at 10- to 15-psi overpressure levels. High reflective paints may be expected to deteriorate from thermal effects at 15-psi levels and above.

C. Blast Effects

To withstand successfully the air blast effects of a nuclear weapons attack, a mobile control center vehicle must maintain:

Stability--a capability to resist the overturning forces that are caused with overpressure, both under sliding and non-sliding conditions, and to be able to experience sliding without harmful effects.

Structural integrity--that is, sufficient strength of body and projections so that buckling or significant deformation and penetrations from flying debris will not occur.

1. Stability. Calculations have been made at 10- and 25-psi overpressure levels for (a) an idealized or hypothetical vehicle, and (b) an adapted existing vehicle. An initial overpressure impulse including reflected overpressure and drag has been applied until the net horizontal pressure is relatively constant. This was

to see if initial shock would overturn the vehicle. Net horizontal pressure was then evaluated. Effects as to sliding were checked, using a coefficient of friction of 0.50. A summary of the pressure history calculations is shown as Exhibit C in the Appendix. The calculations are approximate in that they do not take into effect such variables as the change in pressure quantities during sliding, the change in vertical plane orientation of the side of the vehicle, and the angular momentum during initial tipping of the vehicle. They are, however, considered to be sufficiently refined for the conclusions that were sought.

(a) The idealized vehicle considered has a configuration as shown in Exhibit D of the Appendix. Overturning characteristics were investigated for 10- and 25-psi overpressure levels for a 100-ton total weight vehicle, which means somewhat thinner shielding than that used for the Model 90, and for a 200-ton vehicle. A 32-ton total weight vehicle with the same configuration was also investigated for 10- and 25-psi levels to illustrate the problems involved with an essentially unshielded vehicle.

At 10-psi overpressure, the 200-ton vehicle is stable, as shown. The 100-ton vehicle was calculated to require a distance out to out of wheels or outrigger of approximately 18 feet to resist overturning. The 32-ton vehicle requires a width of 55 feet.

The 200-ton and 100-ton vehicles at 25-psi overpressure were calculated to require out to out distances of wheels or outriggers of approximately 38 feet and 76 feet, respectively, to be stable against overturning. These calculations for the hypothetical vehicle are shown in Exhibit D of the Appendix.

All four of the vehicles investigated, unless restrained by outside forces, will tend to slide when the blast pressures strike the vehicle perpendicular to its longitudinal axis. This tendency will of course reduce, and a tendency toward rolling will appear, as the overpressure force approaches the direction of the longitudinal axis. This sliding on firm hard packed ground, such as a dry lake with a minimum opportunity for the wheels to key into the ground, could theoretically be for a distance of as much as 10 feet at the 10-psi overpressure level of a 5-MT single weapon.

(b) The existing vehicle used for stability calculations is the LeTourneau-Westinghouse Model 90 Haulpak Bottom Dump. This vehicle, which is described in detail in section III B of the report entitled "Vehicle Capabilities, Ground Vehicles" and shown as Exhibit I in the Appendix, was selected primarily because it is commercially built for a 90-ton payload. The trailer portion of this tractor trailer vehicle is approximately of the dimensions required for the van section of a control center vehicle. The weight of 1-3/4 inches of lead plus 1/2 inch of structural steel and 2 inches of timber (as the weight equivalent of the insulation or oblative covering that might be used) was distributed. An additional 7.5 tons of weight was provided for electronic and operational gear. The shape of the body was, for simplicity, considered to be essentially rectangular in shape.

The overturning force resulting from the 10-psi overpressure level cannot be successfully resisted by this vehicle. The wheel track distance (distance c-c of tire treads) is too small. Four feet of additional track width or a track distance of 14 feet is required to resist overturning. Two-foot long outriggers on each side of the vehicle would also suffice. Sliding may be expected to occur and provisions are required for this particular vehicle to prevent it from jack-knifing and to make it act as a unit.

An overpressure of 25 psi would require a track distance between wheels, or outriggers, of 64 feet to prevent overturning. Summarized calculations for the overturning characteristics of the Model 90 Haulpak are shown as Exhibit E in the Appendix.

2. Structural Integrity. The vehicle body and projections must be designed for the selected overpressure. Preliminary calculations indicate that either a rectangular or semi-cylindrical configuration can be provided with a skin over a structural ring and bulkhead framework for the 10-psi level, and probably higher, without complications.

IV VEHICLE CAPABILITIES

While, as previously noted, this study is quite cursory and perhaps is liable, in some respects, to contradiction or contest, it does not appear that any presently developed ground effects machine or ground vehicle can be adapted to satisfy all the criteria. If various trade-offs and downgradings of criteria are considered, it seems that there are some things that can be done, and these appear to be of interest.

A. Ground Effects Machine

The advent of the ground effects machine as an alternate for wheeled or tracked vehicles has attracted considerable interest because of the greater mobility inherent in its principle of operation. Since 1958 about forty different experimental GEM's have been built throughout the world. It is anticipated that in two years several machines will be on the market and their practicality can be measured. At the present time, however, it cannot fulfill the requirements of this study. Units that could carry the personnel and loads of a control center, let alone shielding, are still in the drafting-board and early development stages with many basic problems still to be solved.

1. Types of GEM's

A typical GEM is a rectangular or circular platform with a flat or boat-shaped bottom. It is equipped with fans or jets which create excess air pressure under the base of the platform, supporting it at some distance "H" above a ground or water surface.

Most frequently this pressure is generated and maintained under a partially sealed condition by an annular jet curtain. Outside horizontal or tilted propeller units may also be provided for lateral thrust. Illustrations of some of the GEM's developed or conceived are shown in Exhibit F of the Appendix.

In terms of performance there are three classes of GEM's:

High-Augmentation Vehicles - Bulk-transport carriers operating at ratios of height off the ground to vehicle diameter (H/D) of 0.1 or less.

Low-Augmentation Vehicles - General support craft operating over an H/D range of 0.2-0.8 (or to fringe of free air operation).

Full-Range Augmentation Vehicles - V-Stol - Craft operating mainly in free flight outside the air cushion and above H/D values of 0.8, but using the air cushion for landing.

Development effort has been concentrated in the high-augmentation category for high-speed amphibious load carriers.

Saunders-Roe SR-N1 Hovercraft - An experimental model of this unit has crossed the English Channel. It has a 4000-lb. payload, is 32 feet long by 25.6 feet wide and 10 feet in height. It has a range of 25 miles with a hovering ceiling of 0.7 feet when fully loaded. Maximum speed is 30 mph. Its normal gross weight is 8,700 lbs., and its normal cushion loading is 16 psf. A 40-ton unit is expected to be undergoing operational trials in less than two years. This unit will weigh 100 tons, be 130 feet long and will hover one to four feet above ground.

Curtiss-Wright 2F-1780 - This is a proposed air boat to transport cargo or personnel over land or water. The cargo floor has a capacity of 100 psf. The body is of aluminum. It is 87 feet long by 34 feet wide with a payload capacity of 14,000 lbs. Speed over land is 30 mph.

Development work on large nuclear-powered GEM's is being carried on by Convair under Navy contract. These units would be for long over-ocean flights. A single continuous annular jet would be provided along the periphery of the vehicle. The base pressure would be around 30 psf. A platform 720 feet by 245 feet and a 400-foot diameter circular unit are being considered. The circular unit would be 62.5 feet high at the tail fins; a gross weight of 4 million pounds with a payload of 500 tons; speed of 100 knots. Range, 3000 miles, and a hovering altitude of about 12-15 feet.

A 55,000-pound all up weight unit has been proposed for cargo service in the Bahamas but is still in the early development stages.

Several smaller units are being developed and tested. Some of these are listed below:

Princeton X-3 - an experimental unit designed by the Forrestal Research Center at Princeton for the Army. This unit is 20 feet in diameter, with a gross weight (including pilot and fuel) of 1070 lbs. Its maximum ground speed is 20-25 mph and maximum ground clearance is 12-14 inches.

Curtiss-Wright 2500 Air Car - a 21-foot long by 8-foot wide GEM, with a 1000-lb. payload, 60-mph speed, and hover height of 6-12 inches.

Gyrodyne 55 - a one-man GEM, 9 feet by 6 feet, with a 265-lb. payload. The U.S. Navy is sponsoring this unit as a source of data for future 1000-mph GEM's several hundred feet in diameter.

Bell Air Scooter - also a one-man unit with a hover height of 2-1/2 inches. It has a cruising speed of 25 miles per hour.

Spacetronics Inc. has a military project for a 275-hp, 8-man GEM with a speed of 85 knots.

The Ford Motor Car has been active in the development of a unit called the "Levapad." This differs from other GEM's in that it is supported by a thin air film creating a uniform air pressure of 25-50 psi rather than an air cushion. A very level surface is required with practically no breaks in the surface as the height of the vehicle above the surface is approximately 0.01 inch. This unit has been demonstrated as a "Glidair" and is proposed as an air-cushioned monorail form of inter-city high-speed transport.

Britten-Norman Ltd. of England has developed an annular jet GEM with a 170-hp automobile engine and an unloaded weight of one ton. Pitching pborlems had limited its flight to within its hangar.

Many organizations are interested in the GEM. Some of these are listed in Exhibit G of the Appendix.

2. Operating Characteristics

(a) Weight Ratio. In general the gross weight of commercial or unshielded GEM's will be approximately twice the payload weight.

(b) Horsepower. The horsepower requirement is approximately 400-500 per ton of gross weight. This increases as the cruise height increases, for example:

Gross Weight	17.5 tons	17.5 tons
Speed	60 knots	60 knots
Cruise Height	2 feet	1 foot
Horsepower	7500	4500-5000

(c) Cushion Pressure. The probable maximum cushion pressure for heavy payload units will be 50-100 psf.

(d) Control. A GEM has considerable resistance to forces or moments tending to vary the hover height or causing pitch or roll. However, because it has no effective ground contact it has no resistance to skidding. The Hovercraft SR-N1 is reported to have a distressing skidding tendency in turns.

Unless specific control measures are taken, lateral motion of the machine is resisted only by the inertia of the machine. Methods to combat this lack of control consist of directing peripheral jets sideways to compensate for the side force and tilting of the machine.

GEM's have no stability in Yaw and vanes perpendicular to the annular jet or the provision of differential external thrust are required to minimize this control weakness.

(e) Maneuverability. Acceleration of a GEM to cruising speed is probably in the range of 0.05 to 0.10 g. Deceleration is limited to approximately 0.15 to 0.2 g. Uphill or side slope travel is limited to slopes of 10% or less. Typical turning ability, if direct engine thrust or side-force due to side-slip is used to supplement the low speed jet maneuvering system, is as follows:

at 12 miles per hour turning circle is 110-foot radius;

at 80 miles per hour with 1/2 radian side-slip, the turning radius is 490 feet.

(f) Size. Size and shape allow considerable latitude because the platform unit loading will generally remain constant irrespective of size and speed. Conservative length/beam ratios of 1.5 are used to minimize roll stability problems. A feel for relative sizes is furnished by R. Stanton-Jones of Hovercraft at the 1961 meeting of the Institute of Aerospace Sciences as follows: "For commercially competitive machines which need to operate at $\frac{H}{L} = 0.02$, the size of machine which operated at an H of 1 foot would be about 50 feet long by 20 feet wide and weigh 25 tons, while a vehicle operating at 4-foot hover height would be about 200 feet long, and hence about 16 times the area, or about 400 tons all up weight.

(g) Speed. Indications are that speeds from 25 mph to over 100 mph will be available as GEM's are produced. Visibility problems occur at low speeds because of dust or spray. The minimum for over-water travel, for example, with a cushion loading of 30 psf, has been stated to be approximately 45 mph.

In summary, the principal objection to GEM's is that the control and maneuvering characteristics of presently conceived GEM's would certainly rule it off the roads where even a side wind would make it unmanageable and would restrict its use to over-water or flat clear areas such as deserts and plains. Even here there is great doubt as to its ability to resist destruction by weapon air blasts.

B. Ground Vehicles

Numerous high payload ground vehicles are in use for commercial and military purposes. Both on-road and off-road units exist. Table 3 gives a list of vehicles that were considered. The problem is the term "high payload." When used in this study it implies a capacity to carry shielding for nuclear radiation with consequent payload weights of over 90 tons. This immediately lowers the selection down to one or two vehicles. Normally 15 to 30 tons is considered the high payload bracket.

1. Types. Initially three types of ground vehicles were considered:

Tracked,

Air bag supported, and

Wheeled vehicles.

(a) Tracked Vehicles - These are not of particular interest. With the present tire technology and modern power drives, the relative mobility of the tracked vehicle and wheeled vehicle no longer greatly favors the tracked vehicle as it did in the past. The reaction of tracks and gears to thermal effects is

TABLE 3
HIGH PAYLOAD GROUND VEHICLES

Name	Environ't	Manufacturer	Payld.	Gr.Wt.	HP	Speed	Size	Remarks
Goer Model 60 Haulpak	Anywhere Off-road	LeT-West'se LeT-West'se	15T 60T		274 550	30 46.6	29'-4" x 14'	Rockwagon
Euclid Teracruzer	Off-road Level surface	Euclid 4-Wheel Drive Auto.Co.	25T 10T	20T	340	40 Rds. 25 XCtry		End dump Air Bag to carry Matador, 8 - 5' x 42" 26 tires
Trailer Erector	Road	Rogers Bros. Firestone T&R	50T 5-1/2T		375	35	10'W, 45'L	Self-Prop.,4-Wheel Missile Loader (Corporal)
T58	Xctry & Highway	Detroit Arsenal	16T 25T	39T 48T	540		175" Whl Base 8 x 8	For cargo and missile use
	Highway	Berliot	100T		450		8 Wheel Drive	
AP40	Off-road	Auto Car	40T		600	33		
AP15	"	"	15T					
AP25	"	"	25T					
Wheelless Truck	Off-road	Albee- Rolligan	7T		185	41	6 x 6	Load on Bags - 6 -- 40x50" Bags
Sno-Freigh- ter	Off-road	LeTourneau	150T		2400		274'L, 6 Sect. 16'4" Width, 17'6" Height	Each car on 4 electric wheels
Sno-Buggy	Off-road	LeTourneau		23T	400	8	12-1/2' High, 24"W,27-1/2'L	8 tires 10' x 4'
Rock Earth- hauler	Off-road	Euclid	50T		2300	32-38	Body 22-1/2' x 11-1/2' inside	10 tires
Model 90 Haulpak	Off-road	LeTourneau- Westinghouse	90T	128.7T	550	28.4	Total 56'- 1" x 12'-7"	Coal hauler for Strip Mines

highly suspect. Tracked vehicles have much greater maintenance problems than have wheeled vehicles. Statistics presented by Major Gen. N. M. Lynde Jr., Asst. Chief of Ordinance, U.S.A., show that tracked vehicles have a 3% probability of reaching 4000 miles without failure of a major component.

(a) Air Bag - Air bag or pillow wheel vehicles do not appear to have any great advantage over wheeled vehicles. The low bag pressures used would require unreasonably large bag areas for the payloads being considered. These bags, for flexibility, necessarily have a relatively thin cross-section and would be expected to be quite susceptible to thermal effects. Their present use has been limited to maximum loads of about 10 tons. Two examples of these vehicles are the Auto-Car Teracruzer, which has a 10-ton capacity and was developed to carry the Matador missiles; and the Albee Rolligan, a 7-ton payload off-road truck with six 60" x 50" bags.

(c) Wheeled Vehicles - No wheeled vehicles capable of being adapted to comply with the initial criteria of this report have been found. The width and/or weight requirements to maintain stability against overturning with or without shielding for nuclear radiation, far exceed the present limitations of either on-road or off-road vehicles. The payload requirements for complete nuclear radiation shielding of the square footage of operational space considered necessary are also beyond the limits of existing on-road or off-road vehicles.

Existing wheeled vehicles were also evaluated to see if, with adaptation, any of them could withstand the weapons effects at the 10-psi range. Here again the width and/or weight requirements for stability and the payload requirements for shielding exceed the limits of on-road vehicles.

Certain of the largest off-road vehicles appear to be of interest for this condition. These vehicles are used in heavy excavation and in the military transport fields. They are:

LeTourneau Overland Train Unit
LeTourneau -Westinghouse Model 90 Haulpak
T58 Detroit Arsenal Truck
LeTourneau-Westinghouse "Goer"
Auto Car AP40 Rock Wagon
LeTourneau Westinghouse Model 60 Haulpak

Overland Train Unit - The LeTourneau overland train unit is of interest for two reasons. First, although it is really a train of six units rather than a single vehicle, it carries the heaviest payload, 150 tons, of any vehicle investigated. It has been in use as an Arctic cargo hauler. Second, it employs the individual wheel electric drive system which is more easily adapted to new or unusual body requirements than the central drive system and, in addition, provides traction at every wheel. A 13-unit train of about the same capacity has been contracted for by the Army Transportation Corps. The speed of this train is approximately 20 miles per hour. Each wheel has a tire 10 feet in diameter and 4 feet wide.

One problem that presents itself in considering an adaptation of one of these trains is that each train unit has a payload capacity of 30 tons or less. This means that each unit would probably be able to carry something in the order of 50 square feet floor area fully shielded operational area van and that many of these would be required to aggregate the required square footage of van space. It is felt that the inter-relationships of the personnel and the functions they perform in a control center would make such an arrangement undesirable. Three units are probably a workable limit. There is also some question as to the difficulty of maintaining the stability of a train and the reaction of each unit on the train as a whole when subjected to overturning and sliding forces. The ratio of surface area subjected to overpressure to operational floor area would be high with a multiple unit train in comparison with single or double unit vehicles such as a tractor trailer.

It is felt that the LeTourneau approach to body construction and vehicle drive is of interest and that many of the features of their large vehicles would facilitate the development of a mobile control center but that the train itself cannot be readily adapted as a 10-psi vehicle. Illustrations of the train are shown in Exhibit H of the Appendix.

<u>Model 90 Haulpak</u> - The LeTourneau Model 90 Haulpak is perhaps the nearest thing to a vehicle that could be adapted that is available. Designed as a high-speed coal transport for strip mines, it is a tractor trailer unit with a payload capacity with its present body of 90 tons. This is the highest payload that was

found with the exception of the LeTourneau train units. It is driven by a 550-hp diesel and has a top speed of 28.4 miles per hour. This appears to be the only vehicle that could approach the operational floor area requirement, as one area, shielded for complete protection against the nuclear radiation from the 10-psi overpressure level attack No. 2 or national fallout threat as arrived at in Section III, "Weapons Effects." Specifications and illustrations of this vehicle are shown in Exhibit I of the Appendix. Adaptation factors for this vehicle are discussed in Section V, "Adaptation."

T-58 Truck - The T-58 Detroit Arsenal Truck is the largest payload military vehicle for off-road use that seems to be available. This is an 8 x 8 wheel unit with an off-road payload capability of 16 tons transported, or 18 tons towed. This vehicle could not accommodate the shielding weights required for 10-psi range nuclear radiation and is presented only in the event that weapons effects requirements are downgraded to include stability, thermal effects and token or partial shielding.

Goer - The LeTourneau-Westinghouse Goer is a military vehicle for logistical operations and was developed for the Army. It has extreme off-road mobility and a maximum speed of 32.5 miles per hour. It has a low center of gravity and with outriggers could probably be adapted to be quite stable. It has only a 15-ton payload, however, and is therefore too light a vehicle. It could be of some interest for adaptation as a one-man or two-man control center with minimum capabilities provided zone or token shielding was satisfactory. This has not been explored beyond the observation that shielding for the 10-psi level attack No. 2 or national fallout levels as previously discussed would weigh approximately 105 pounds per square foot of shielded surface.

On the assumption that 6 tons of the payload would be available for shielding, approximately 115 square feet of lead shielding could be provided.

This much area approximates the requirements for the driver alone. Data on the Goer is included in Exhibit J of the Appendix. Second or third generation larger Goers may well be attractive as they seem to be a move in the right direction.

<u>Model 60 Haulpak and AP40</u> - The LeTourneau-Westinghouse Model 60 Haulpak and Auto Car AP40 are conventional rock excavation trucks with an off-road capability to carry 60-ton and 40-ton payloads, respectively. These vehicles have no particular features to recommend them for the use prescribed in this report and information is presented on them in Exhibit K of the Appendix only to illustrate the characteristics of off-road construction trucks available from various companies. Although they indicate a familiarity in the transport field with off-road conditions and high payloads, they show the tendency toward highly specialized vehicles, vehicles that do not lend themselves to adaptation for other uses.

V ADAPTATION

Certain adaptation factors for mobile control centers, such as fuel storage and personnel accommodations for extended travel range, are common to so-called land-cruiser vehicles such as petroleum exploration units, and not peculiar to mobile units in a nuclear attack environment. These factors are considered to be outside the interest of this particular study.

Other factors involving the equipment required for the control functions, for communications gear, air conditioning, etc., which are in part common to present electronic equipment vans and in other respects common to fixed "hard" installations, are also considered beyond the scope of this study.

Adaptation factors peculiar to mobile control centers in a nuclear attack environment have been established in some degree in Section III, "Weapons Effects," of this report. This section deals with some of these for the 10-psi level weapons effects as applied to a specific vehicle, the Model 90H Haulpak--not to solve the problems of adapting the Model 90 but to indicate an example of major areas requiring changes in existing vehicles.

Body - An entirely new body would be required for the trailer portion of the vehicle. This body would be streamlined for minimum overturning forces. It would be expected to have walls of a multi-layered cross-section consisting (not necessarily in this order) of a light-colored reflective paint, an oblative or charring material, an insulating material, a structural skin, lead shielding, and structural diaphragms or pressure rings.

It is estimated that the total weight of the body, for which preliminary calculations indicate 1-3/4 inches of lead for shielding and a structural system comparable to 1/2 inch steel plate with 16-inch deep pressure rings every 30 inches, complete, will be between 90 and 100 tons. This is some 30 to 40 tons less than the gross trailer weight of the existing vehicle, giving what seems to be an adequate weight allowance for accessories, gear, personnel, etc. The driver's cab would require the same construction. The rest of the tractor could remain unshielded.

Wheels - The track distance must be widened by a total of 4 feet or by the provision of equivalent steel outriggers on each side of both the trailer and tractor. Larger lower pressure tires must be provided to lower the soil loading values of the vehicle. They are high now because the vehicle is used on hauling roads and is equipped with high-pressure rock service tires. To minimize the possibility of tire loss through surface ignition from thermal radiation, the maximum ply tire available should be used with the anticipation that a surface layer could be burnt off and the tire would still survive. A wheel pant or renewable shade seems desirable. This would hang over the side of the wheel to shade the tire sidewall and incidentally shade the wheel hub to avoid the possibility of bearing seizure.

General - Inasmuch as the cab is to be totally enclosed, a combination of periscope and closed-circuit television would be required for operational control. Blast-proof closures for personnel access and air intakes are necessary.

Summary - There is considerable doubt as to the reasonableness of adaptation of an existing vehicle to create a military mobile control center. Even though one or two vehicles appear to have basic characteristics as to payload and power plant that fit the needs, it is felt that the costs involved when detail military type design specifications are established might well indicate that it would be more reasonable to develop a new vehicle using existing components.

<u>EXHIBIT A</u>

REFERENCES

References

1. "The Effects of Nuclear Weapons," 1957
   U. S. Department of Defense.

2. "Techops Report No. TO-B 60-13," Dec. 1, 1960

3. Corps of Engineers Manual #EM 1110-345-413, "Design of Structures to Resist the Effects of Nuclear Weapons"

4. Radiological Recovery of Fixed Military Installations, NAVDOCKS TP-PL-13

5. "Preliminary Stability, Control and Handling Criteria for Ground Effect Machines (GEMS)" by N. K. Walker.
   IAS Paper #61-69

6. "Tranlational Characteristics of Ground Effect Machines," by Winston W. Royce and Scott Rethorst.
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7. "Some Design Problems of Hovercraft" by R. Stanton Jones.
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8. "GEM Design Philosophy for an Over-Water, Over-Ice Vehicle," by Olle Ljungstrom
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9. "An Approach to the Operational Features Desirable in a Military Acceptable GEM," by P. G. Fielding.
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10. "A Conceptual Nuclear Propulsion System for Ground Effect Machines," by J. C. Westmoreland, J. B. Dee and J. E. Loos
    IAS Paper #61-46

11. "Basic Principles of the Stability of Peripheral Jet Ground Effect Machines," by Michael C. Eames
    IAS Paper #61-71

12. "Ground Effect Machine Propulsion System Design Consideration," by L. W. Norman
    IAS Paper #61-48

13. Space Aeronautics, June 1960

14. All references to Ground Vehicles and GEMS from 1950 to 1961 as listed in Industrial Arts and Index and the Engineering Index.

EXHIBIT B

INITIAL AND RESIDUAL RADIATION DOSES

INITIAL AND RESIDUAL RADIATION DOSES

5-MEGATON SURFACE BURST

Peak Overpr. (psi)	1	2	3	4	5	10	15	20	25
Distance (miles)	14	9	6.8	5.7	5.0	3.2	2.5	2.4	2.1
Initial Gamma Radiation (R)	<10	<10	<10	<10	<10	<10	30	52	200
Initial Neutron Radiation	<10	<10	<10	<10	<10	<10	<10	<10	85
Residual Radiation--Attack #1									
Scale Factor = $W^{1/3}$	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71
d ÷ $W^{1/3}$	8.2	5.3	4.0	3.3	2.9	1.9	1.5	1.4	1.2
1-Hr Ref. Dose for 1-MT (R) (Assume maximum dose)	3000	3000	3000	3000	3000	3000	3000	3000	3000
Actual 1-Hr Ref. Dose (R)	5130	5130	5130	5130	5130	5130	5130	5130	5130
Time at Start of Fallout (Hrs)	0.93	0.61	0.45	0.38	0.33	0.21	0.17	0.16	0.14
Factor for Accum.Dos (Start)	6.4	5.9	5.5	5.2	5.1	4.6	4.2	4.1	4.0
Factor for Accum. Dose at 168 Hrs.	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Difference	3.1	3.6	4.0	4.3	4.4	4.9	5.3	5.4	5.5
Actual Dose (1000's of R)	15.9	18.5	20.6	22.1	22.6	25.2	27.3	27.8	28.3

General Notes

(1) Distance and Initial Radiation based on Corps of Engineers Manual #EM 1110-345-413;
(2) Remainder based on Effects of Nuclear Weapons.

INITIAL AND RESIDUAL RADIATION DOSES

10-MEGATON SURFACE BURST

Peak Overpr. (psi)	1	2	3	4	5	10	15	20	25
Distance (miles)	18.0	12.0	8.8	7.0	6.2	4.2	3.5	3.0	2.7
Initial Gamma Radiation (R)	<10	<10	<10	<10	<10	<10	20	110	340
Initial Neutron Radiation	<10	<10	<10	<10	<10	<10	<10	<10	<10
Residual Radiation Attack #1									
Scale Factor = $W^{1/3}$	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15
$d \div W^{1/3}$	8.4	5.6	4.1	3.2	2.9	2.0	1.6	1.4	1.3
1-Hr Ref. Dose for 1-MT (R) (Assume Maximum Dose)	3000	3000	3000	3000	3000	3000	3000	3000	3000
Actual 1-Hr Ref. Dose (R)	6450	6450	6450	6450	6450	6450	6450	6450	6450
Time at Start of Fallout (Hrs)	1.20	0.8	0.59	0.47	0.41	0.28	0.23	0.20	0.18
Factor for Accum.Dose (Start)	6.5	6.1	5.8	5.5	5.3	4.8	4.5	4.4	4.3
Factor for Accum. Dose at 168 Hrs.	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Difference	3.0	3.4	3.7	4.0	4.2	4.7	5.0	5.1	5.2
Actual Dose (1000's of R)	19.4	21.9	23.8	25.8	27.1	29.6	32.2	32.9	33.6

INITIAL AND RESIDUAL RADIATION DOSES

20-MEGATON SURFACE BURST

Peak Overpr. (psi)	1	2	3	4	5	10	15	20	25
Distance (miles)	24	15	10.1	9.0	8.0	5.3	4.5	3.7	3.4
Initial Gamma Radiation (R)	<10	<10	<10	<10	33	110	500	2600	5200
Initial Neutron Radiation	<10	<10	<10	<10	<10	<10	<10	<10	<10
Residual Radiation-Attack #1									
Scale Factor = $W^{1/3}$	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71
$d \div W^{1/3}$	8.8	5.5	3.7	3.3	3.0	2.0	1.7	1.4	1.3
1-Hr Ref. Dose for 1 MT (R) (Assume maximum dose)	3000	3000	3000	3000	3000	3000	3000	3000	3000
Actual 1-Hr Ref. Dose (R)	8130	8130	8130	8130	8130	8130	8130	8130	8130
Time at Start of Fallout (Hrs.)	1.6	1.0	0.67	0.60	0.53	0.35	0.30	0.25	0.23
Factor for Accum. Dose (Start)	6.7	6.4	6.0	5.9	5.6	5.1	4.9	4.6	4.5
Factor for Accum. Dose at 168 Hrs.	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Difference	2.8	3.1	3.5	3.6	3.9	4.4	4.6	4.9	5.0
Actual Dose (1000's of R)	23.8	25.2	28.4	29.2	31.7	35.8	37.4	40.0	40.6

EXHIBIT C

PRESSURE HISTORY

PRESSURE HISTORY

I 5 MT, 10 psi

(Refer. Corps of Engineers Manual EM 1110-345-413)

Front Face

1. Initial overpressure = Pso = 10 psi
2. Duration of positive phase = t_o = 4.5 sec. (page 13)
3. h' = clearing height = 10 ft.
4. Velocity of sound in region of reflected over pressure = C_{refl} = 1290 ft. per sec. (page 28)
5. t_c = clearing time for front face $= \frac{3h'}{C_{refl}} = \frac{3 \times 10}{1290} = 0.0233$ sec
6. q_o = Maximum drag pressure = 2.23 (page 32)
7. In the table below:
   t = time measured after arrival of shock wave
   q = unit drag pressure
   Ps = Overpressure at time t
   Ps + 0.85 q = $\bar{P}$ front = average overpressure on front face

t	t/t_o	q/q_o	q	Ps/Pso	Ps	Ps + 0.85q
Sec.	-	-	psi	-	psi	psi
0	0	1.00	2.23	1.00	10.0	12.12
0.45	0.10	0.634	1.40	0.814	8.15	9.48
0.90	0.20	0.397	0.89	0.655	6.55	7.40
1.35	0.30	0.245	0.55	0.519	5.19	5.71
1.80	0.40	0.148	0.33	0.402	4.02	4.33
2.25	0.50	0.087	0.19	0.303	3.03	3.21
2.70	0.60	0.049	0.11	0.220	2.20	2.30
3.15	0.70	0.026	0.06	0.149	1.49	1.55
3.60	0.80	0.12	0.03	0.090	0.90	0.93
4.05	0.90	0.004	0.01	0.041	0.41	0.42
4.50	1.0	0.00	0.00	0.00	0.00	0.00

Note: For reflected pressure build-up, see page 36, C of E Manual.

Back Face

1. U_o = Velocity of incident shock front = 1400 ft. per sec. (12)

2. t_d = time required for the shock front to travel from front face to back face $= \frac{L}{U_o} = \frac{10}{1400} = 0.00714$ sec.

3. t_b = time required for overpressure on rear face to reach its maximum value $= \frac{4h'}{C_o} \quad \frac{4 \times 10}{1115} = 0.0358$ sec $= (t-t_d)$

   where C_o = velocity of sound in undisturbed air.

4. $$\frac{t - t_d}{t_o} = \frac{0.0358}{4.5} = 0.0080$$

5. $$\frac{Ps}{Pso} \left[\text{at } \frac{t-t_d}{t_o} = 0.0080 \right] = 0.984 \text{ (Ref. pg. 31)}$$

6. Ps = Psb = overpressure at back face in incident shock wave when $\left[(t - t_d) = t_b \right] = 10(.984) = 9.84$ psi.

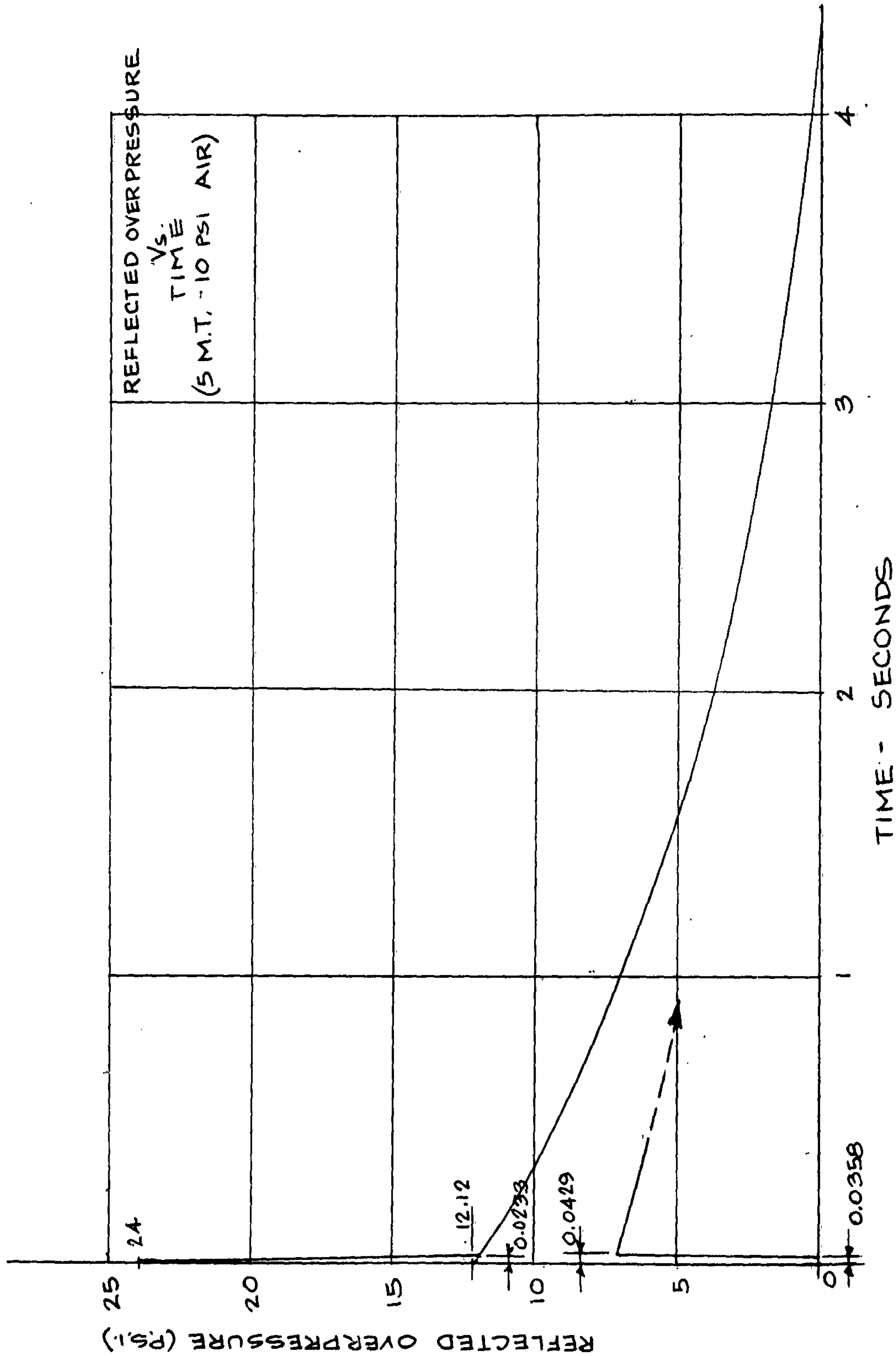
7. $$(P_{back}) \max = Psb \left[1 + (1 - B)e^{-B} \right] \tfrac{1}{2}$$

   $$\left(\text{where } B = \frac{0.5\ Pso}{14.7} = \frac{0.5 \times 10}{14.7} = 0.34 \right)$$

   $$(P_{back}) \max = 0.984 \left[1 + (1 - 0.34)e^{-0.34} \right] \tfrac{1}{2} = 7.22 \text{ psi}$$

Back Face (Cont.)

t	$t-t_d$	$\frac{t-td}{t_o}$	$\frac{Ps}{Pso}$	Ps	$\frac{(\bar{P}\text{ back})\text{ Max}}{Ps}$	$\bar{P}$ back
Sec	Sec	-	-	psi	-	psi
0.0429	0.0358	0.008	0.984	9.84	0.735	7.22
0.457	0.45	0.1	0.814	8.14	0.737	6.00
0.907	0.90	0.2	0.655	6.55		decreases
1.357	1.35	0.3	0.519	5.19		gradually
1.807	1.80	0.4	0.402	4.02		to zero
2.257	2.25	0.5	0.303	3.03		↓
2.707	2.70	0.6	0.202	2.20		
3.157	3.15	0.7	0.149	1.49		
3.607	3.60	0.8	0.090	0.90		
4.057	4.05	0.9	0.041	0.41		
4.507	4.50	1.0	0.	0.		


REFLECTED OVERPRESSURE
Vs.
TIME
(5 M.T. - 10 PSI AIR)
TIME - SECONDS
REFLECTED OVERPRESSURE (P.S.I.)
24
12.12
0.0233
0.0429
0.0358
25
20
15
10
5
0
1
2
3
4

II 5 MT, 25 psi

Front Face

1. Initial overpressure = 25 psi = Pso
2. t_o = 3.5 sec.
3. h' = 10 feet
4. C_{refl} = 1490 feet per second
5. $t_c = \frac{3 \times 10}{1490} = 0.021$ sec.
6. q_o = 13.0 psi

t	t/t_o	q/q_o	q	Ps/Pso	Ps	Ps + 0.85q
Sec	-	-	psi	-	psi	psi
0.	0.	1.0	13.0	1.0	25	36
0.35	0.1	0.634	8.23	0.814	20.3	27.3
0.70	0.2	0.397	5.15	0.655	16.4	20.78
1.05	0.3	0.245	3.18	0.519	13.0	15.7
1.40	0.4	0.148	1.93	0.402	10.1	11.74
1.75	0.5	0.087	1.13	0.303	7.6	8.56
2.10	0.6	0.049	0.635	0.220	5.52	6.06
2.45	0.7	0.026	0.338	0.149	3.73	4.02
2.80	0.8	0.012	0.156	0.090	2.26	2.39
3.15	0.9	0.004	0.052	0.041	1.03	1.07
3.50	1.0	0.	0.	0.	0.	0.

Back Face

1. U_o = 1750 ft. per second

2. $t_d = \frac{L}{U_o} = \frac{10}{1750} = 0.0057$ seconds.

3. $t_b = \frac{4h'}{C_o} = \frac{4 \times 10}{1115} = 0.0358$ sec. $= (t-t_d)$

4. $\frac{t - t_d}{t_o} \quad \frac{0.0358}{3.5} = 0.01025$

5. $\frac{Ps}{Pso}$ (at $\frac{t-t_d}{t_o} = 0.01025$) $= 0.980$

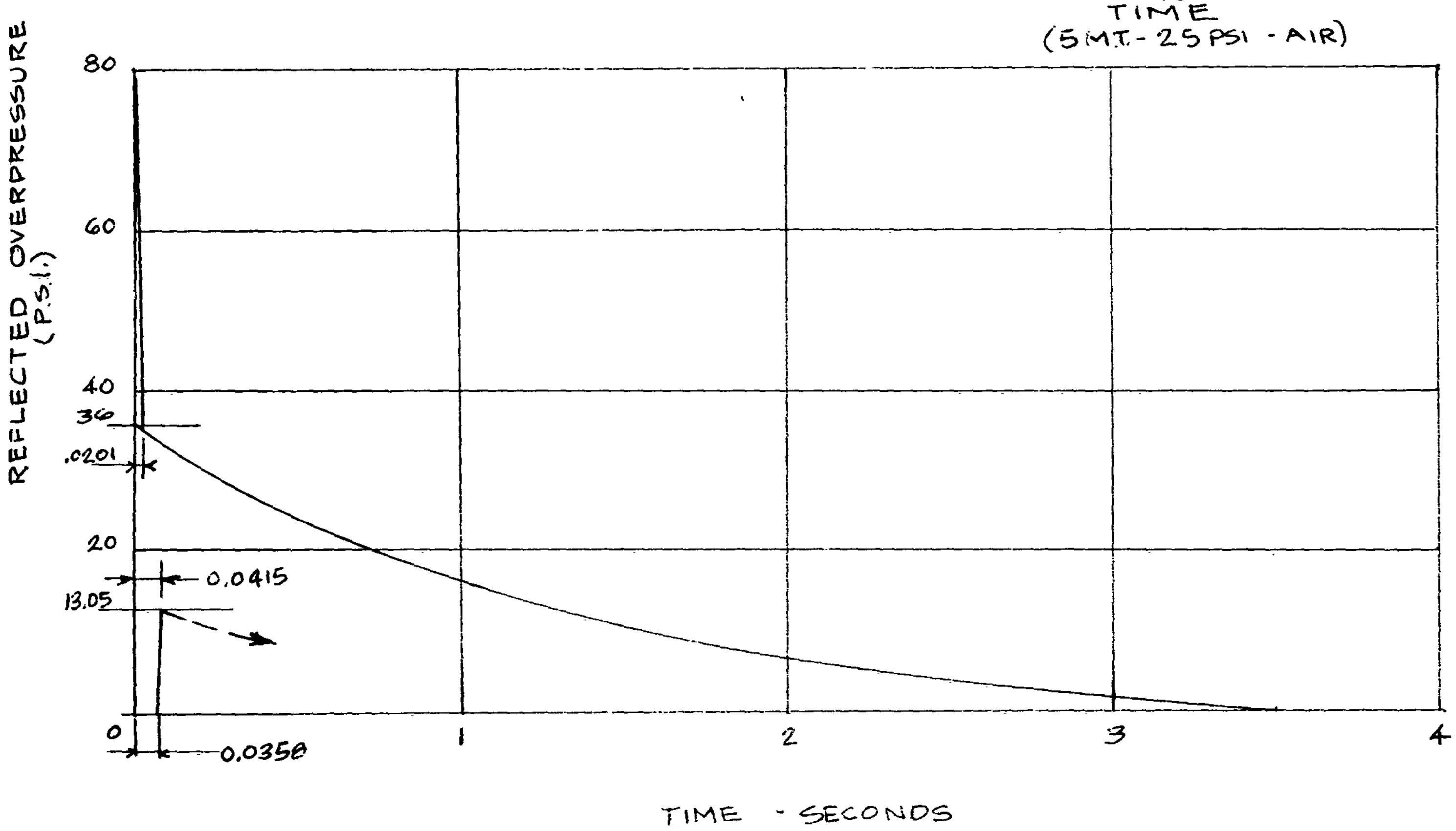
6. $Ps = Psb = 25(0.980) = 24.5$ psi

7. $(P_{back})_{max} = Psb \left[1 + (1 - B)e^{-B}\right] \frac{1}{2}$

(where $B = \frac{0.5\ Pso}{14.7} = \frac{0.5(25)}{14.7} = 0.85$)

$$= 24.5 \left[1 + (1 - 0.85)e^{(-0.85)}\right] \frac{1}{2} = 13.05 \text{ psi}$$

REFLECTED OVERPRESSURE
Vs
TIME
(5 M.T. - 25 PSI - AIR)



INITIAL IMPULSES

I **5 MT, 10 psi**

		lb.sec. per sq.in.
a)	t = o to t = 0.0233 sec.	
	I = (24 - 12.12) ½ x0.0233 + 12.12(0.0233)	
	= 0.1385 + .282 =	0.421
b)	t = 0.0233 sec to t = 0.0358	
	I = 12.12 (.0358 - .0233) =	0.153
c)	t = 0.0358 sec to t = 0.0429 sec	
	I = (0.0429 - .0358) ½ (12 + 7.2) =	0.069
	Total Impulse =	0.643

d) t greater than 0.0429
Consider net horizontal pressure to be 5 psi, decreasing relatively slowly to zero.

II **5 MT, 25 psi**

a)	t = 0 to t = 0.0201 sec.	
	I = 0.02 (80 + 36) ½ =	1.165
b)	t = 0.0201 to t = 0.0358 sec.	
	I = (36 + 34) ½ (.0358 - .0201) =	0.545
c)	t = 0.0358 to t = 0.0415 sec.	
	I = (34 + 20) ½ (.0415 - .0358) =	0.154
	Total Impulse =	1.864

d) t greater than 0.0415 sec.
Consider net horizontal pressure to be 20 psi, decreasing relatively slowly to zero.

EXHIBIT D

IDEALIZED VEHICLE

STABILITY ANALYSIS

I **Idealized Vehicle - (see Page D-2)**

Horizontal area = 50,500 sq. in.

Weight - consider 32 tons, 100 tons and 200 tons.

A. 5 MT, 10 psi

Total Impulse = 50,500 x 0.643 = 32,500 lb. sec.

(1) Weight	(2) Velocity of C.G. Ft./sec.	(3) Kinetic Energy Ft. lbs.	(4) Amount of Rise of C.G. Feet	(5) Remarks
32 T	16.35	265,000	8.3	Unstable
100 T	5.22	84,500	0.422	Stable under impulse
200 T	2.61	42,300	0.106	Stable under impulse

(2) Velocity $= \frac{\text{Impulse}}{\text{mass}}$

(3) K.E. $= \frac{1}{2}\frac{W}{g}(v^2)$

(4) Rise $= \frac{\text{K.E.}}{\text{(wt.) in lbs.}}$

Stability after Initial Impulse under assumed constant pressure = 5 psi.

Total horizontal load = 50,500 x 5 psi = 252,500 lbs.

Moment arm = 7.5 ft.

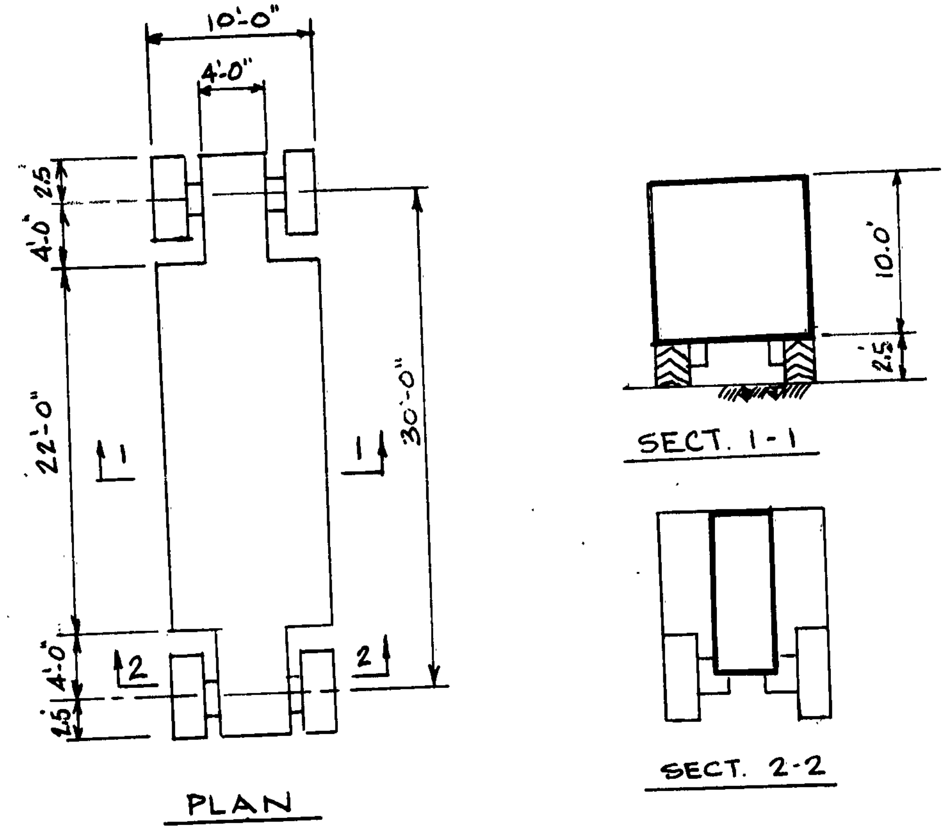
Total over turning moment = 7.5 x 252,500 = 1,770,000 ft. lbs.

Required Radius for Stability:

a) 32T veh - R = 1,770,000/64,000 = 27.7', O. to O. width = 55.4'

b) 100T veh - R = 1,770,000/200,000 = 8.85' " " = 17.70'

c) 200T veh - R = 1,770,000/400,000 = 4.42' " " = 8.84'



IDEALIZED VEHICLE

Sliding

Net horizontal load = 252,500 lbs.

Assume coefficient of friction = 0.5

Required weight (under constant horizontal pressure) =

$$\frac{252,500}{0.5} = 505,000 \text{ lbs.}$$

Therefore, all three vehicles will slide.

Approximate distance of sliding (100-ton vehicle) at t = .04 sec.

$$\text{Accel} = \frac{F}{M} \quad \frac{252,500}{200,000} \times 32.2 = 40.6 \text{ ft. per sec. per sec.}$$

$$\text{Deceler due to friction} = \frac{200,000 \times .5 \times 32.2}{200,000} = \underline{16.1} \text{ ft/sec/sec}$$

Net accel = 24.5 "

at t = 1.5 sec, net pressure = 2 psi$\pm$

Accel = 2/5 x 40.6 = 16.4 ft. per sec. per sec.

Decel = $\underline{16.4}$ "

Net accel = 0.

at t = 0.75 sec, net pressure = 3 psi$\pm$

Accel = 3/5 x 40.6 = 24.4 ft. per sec. per sec.

Decel = $\underline{16.4}$ "

Net accel = 8.0 "

$$\text{Average acceleration} = \frac{24.5 + 4\,(8.0) + 0}{6} = 9.4 \text{ ft/sec/sec}$$

$$S = 1/2\ at^2 = 1/2 \times 9.4 \times 1.46^2 = \underline{10.0'}\pm$$

B. 5MT, 25 psi

Total Impulse = 50,500 x 1.864 = 94,000 lb. sec.

Weight	Velocity of C.G. Ft./Sec.	Kinetic Energy Ft. Lbs.	Amount of Rise of C.G. Feet	Remarks
32T	47.1	2,220,000	-	Unstable
100T	15.1	706,000	3.52	Unstable, needs outriggers
200T	7.55	355,000	0.89	Stable under impulse

Stability after Initial Impulse under assumed constant pressure of 20 psi.

Total horizontal load = 50,500 x 20 = 1,010,000 lbs.

Moment arm = 7.5 ft.

Total over turning moment = 7.5 x 1,010,000 = 7,570,000 lb. ft. lbs.

Required Radius for Stability:

a) 32T veh-R = 7,570,000/64,000 = 119' O.to O. width = 238'

b) 100T veh-R = 7,570,000/200,000 = 37.8' " " = 75.6'

c) 200T veh-R = 7,570,000/400,000 = 18.9' " " = 37.8'

All vehicles are subject to sliding.

Conclusion: 25 psi vehicle seems impractical .

EXHIBIT E

LeTOURNEAU - WESTINGHOUSE MODEL 90 HAULPAK

II LeTourneau Westinghouse Model #90 (see Page E-2)

Horizontal area of trailer = 366.4 sq. ft.

Horizontal area of erector = 86.6 sq. ft.

Weight of trailer - = 217,650 lbs.

Weight of tractor with trailer = 132,800 lbs.

Height of C. G. - Trailer = 6.65'

Height of C.G. - Tractor = 6.1'

Check stability for 5 MT, 10 psi

A. Trailer

Initial Impulse = 366.4 x 144 x 0.643 = 33,900 lb.sec.

Velocity of C.G. = $\frac{33,900 \times 32.2}{217,650}$ = 5.03 ft/sec

Kinetic Energy $(5.03)^2 \times \frac{217,650}{32.2} \times \frac{1}{2}$ = 85,500 lb.ft.

Height that C. G. raises = $\frac{85,500}{217,650}$ = 0.4'

∴ Trailer is stable.

After Initial Impulse, net pressure = 5 psi.

Net horizontal load = 366.4 x 5 x 144 = 264,000 lbs.

Over turning moment = 264,000 x 6.65 =1,760,000 lb.ft.

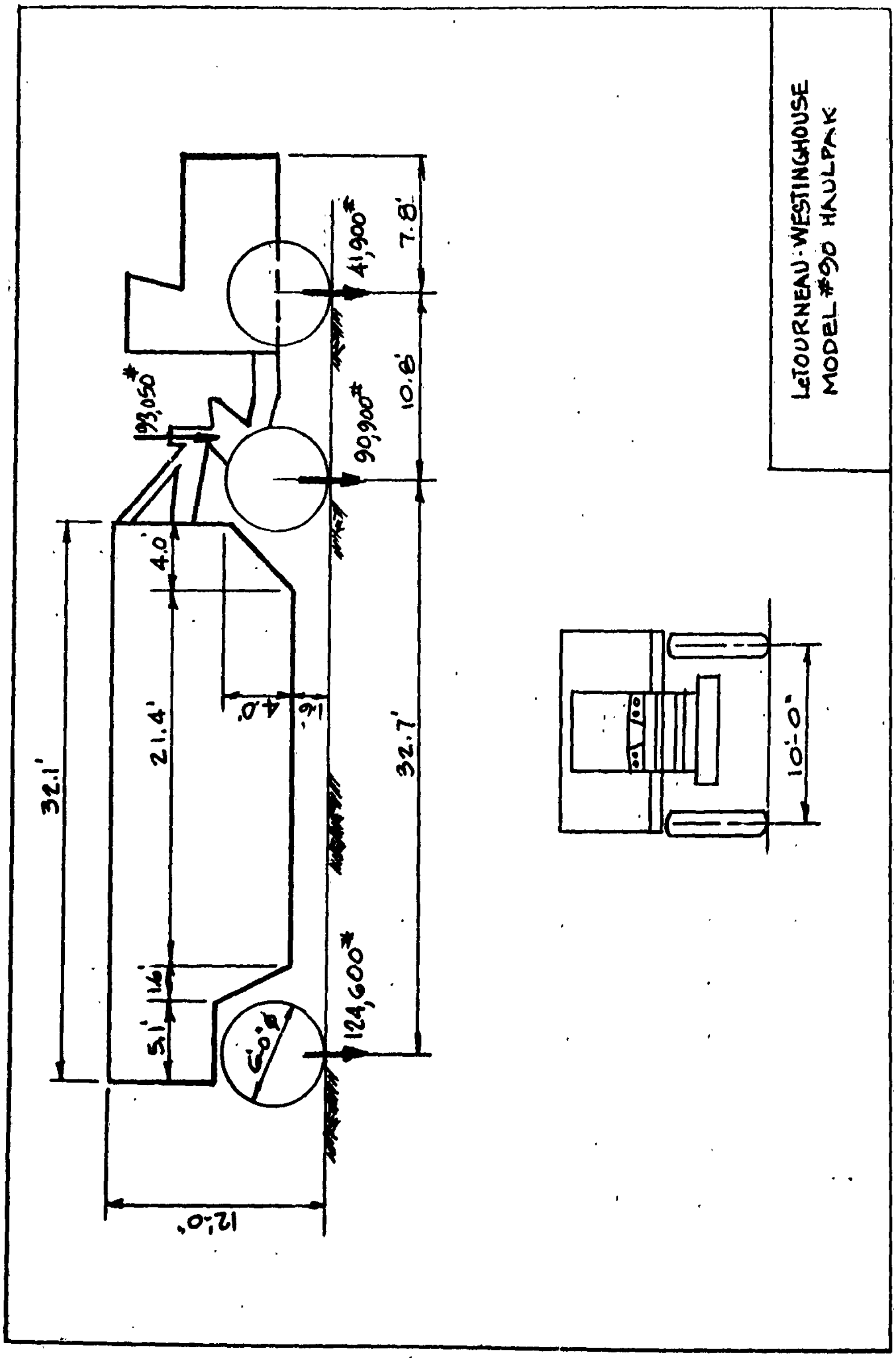
Radius required for Stability = $\frac{1,760,000}{217,650}$ = 8.1'

Required O. to O. width = 16.2'

Have 12'-0"; use outriggers 2.1' from body.

Factor of Safety vs Slide = $\frac{217,650 \times .5}{264,000}$ = 0.41

Therefore, trailer will slide.



LeTOURNEAU-WESTINGHOUSE
MODEL #90 HAULPAK
193,050#
41,900#
90,900#
124,600#
7.8'
10.8'
32.7'
32.1'
21.4'
4.0'
4.0'
1.6'
1.6'
5.1'
6'-0"ϕ
12'-0"
10'-0"

B. <u>Tractor</u>

Initial Impulse = 86.6 x 144 x 0.643 = 8,010 lb.sec.

Therefore, stable by inspection.

After Initial Impulse, net pressure = 5 psi.

Net horizontal load = 86.6 x 5 x 144 = 62,300 lbs.

Over turning moment = 6.1 x 62,300 = 380,000 lb. ft.

Radius required for stability = $\frac{380,000}{132,800}$ = 2.9'

Total width required = 5.8'; have 12'-0".

.·. Tractor is stable.

Factor of safety vs sliding = $\frac{132,800 \times 0.5}{62,300}$ = 1.06

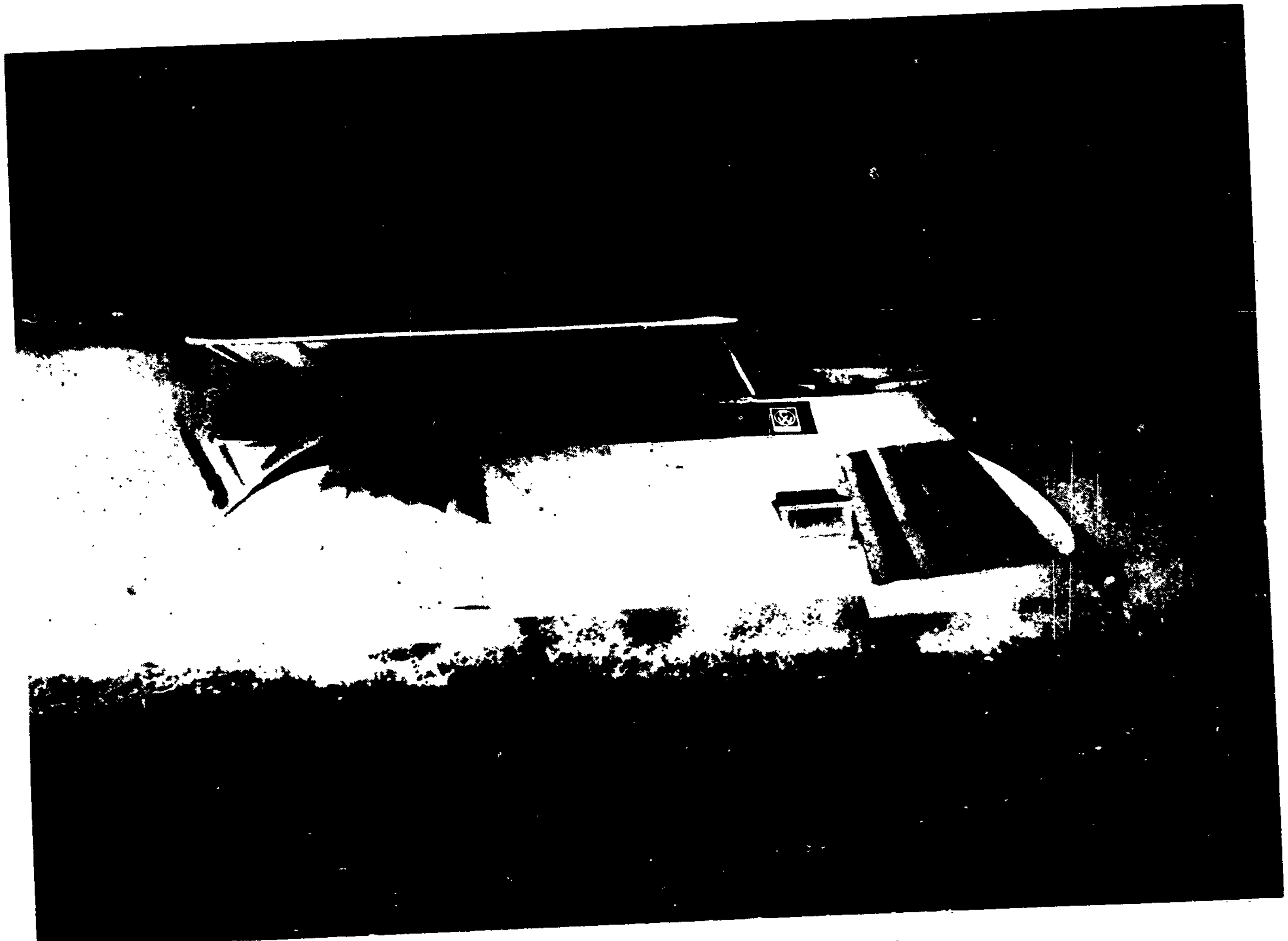
.·. Tractor will probably not slide

but trailer-tractor combination will tend to jackknife.

EXHIBIT F

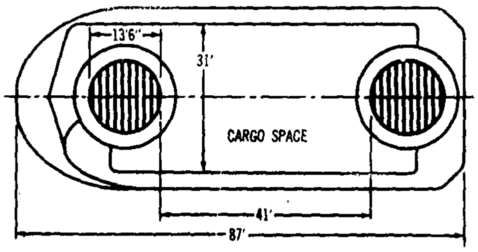
GROUND EFFECT MACHINES

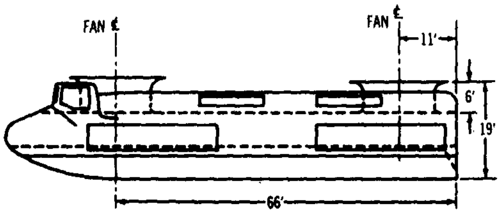
CURTISS-WRIGHT AIR CAR

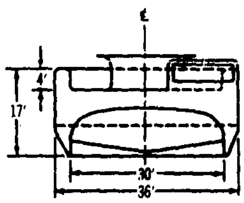


From Columbia Engineering Quarterly, Jan. 1961

CURTISS-WRIGHT 2F-1780

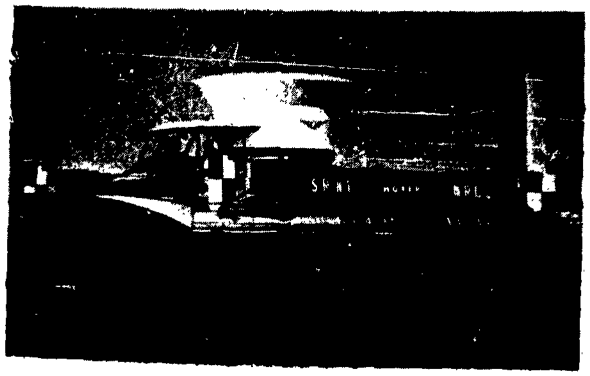






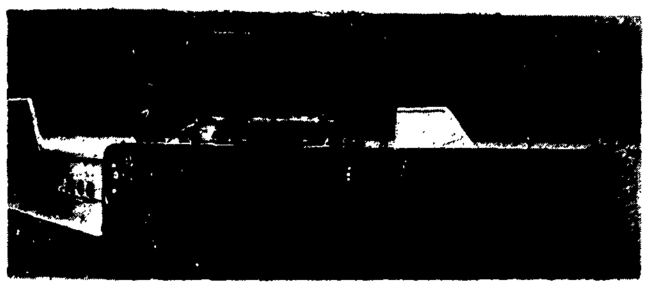
(South Bend Division, Curtiss-Wright Corp., South Bend, Ind.)

SR-N1 HOVERCRAFT

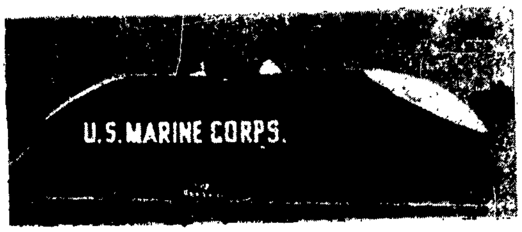


(Saunders Roe Ltd., Osborne East Coews, Isle of Wight)

GEM DEVELOPED BY CARL WEILAND, SWITZERLAND

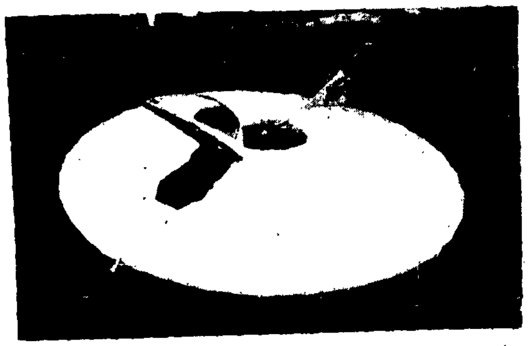


GEM-1



(National Air Research Associates and Pegasus)

PRINCETON X-3



(Forrestal Research Center, Princeton University,
Princeton, N. J.)

MODEL 55 GEM

(Gyrodyne Co. of America Inc.,
St. James, N.Y.)

EXHIBIT G

ORGANIZATIONS ACTIVE IN

GEM DEVELOPMENT

EXHIBIT G

ORGANIZATIONS ACTIVE IN GEM DEVELOPMENT

Army
- Aeronutronic Division Ford Motor Co.
- Auro Aircraft Ltd., Canada
- Princeton University Forrestal Research Center
- Vertol Surcraft

Bureau of Naval Weapons
- Convair Division General Dynamics Corp.
- Gyrodyne Co. of America
- Saunders-Roe Ltd., England

Bureau of Ships
- Hughes Tool Co.
- Martin Co.
- Stevens Institute of Technology

Marine Corps
- National Research Associates

Office of Naval Research
- Aerophysics Co.
- Bell Aircraft Corp.
- University of California
- Cornell Aeronautical Laboratory
- Hiller Aircraft Corp.
- University of Iowa
- Lockheed Aircraft Corp.
- Ryan Aeronautical Co.
- Thermoelectric Co.
- Vehicle Research Corp.
- University of Wichita

Maritime Administration, Research Division

National Aeronautics and Space Administration

Office of Research and Engineering, Department of Defense

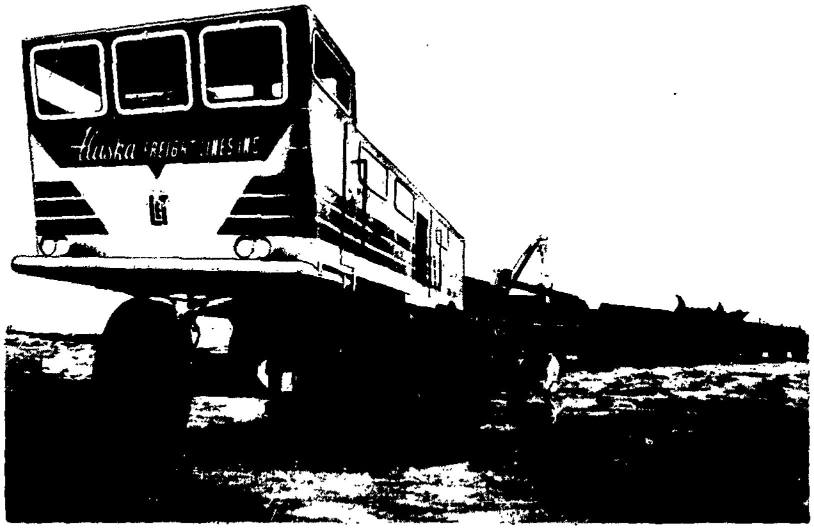
Ordnance Tank Automotive Command, U. S. Army

Transportation Research and Engineering Command, U. S. Army

EXHIBIT H

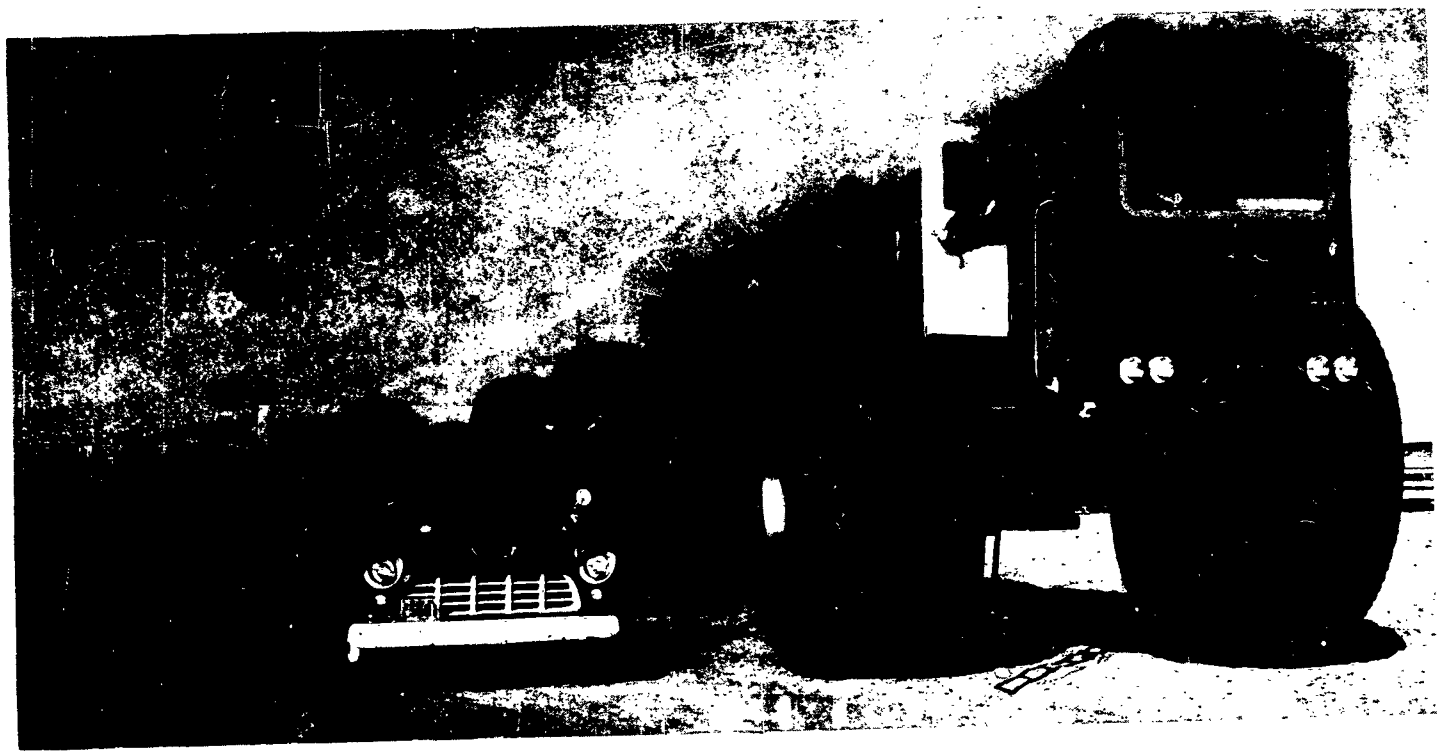
ARCTIC TRAINS

ARCTIC TRAIN



(From R. G. LeTourneau Company Brochure)

CROSS-COUNTRY TRAIN



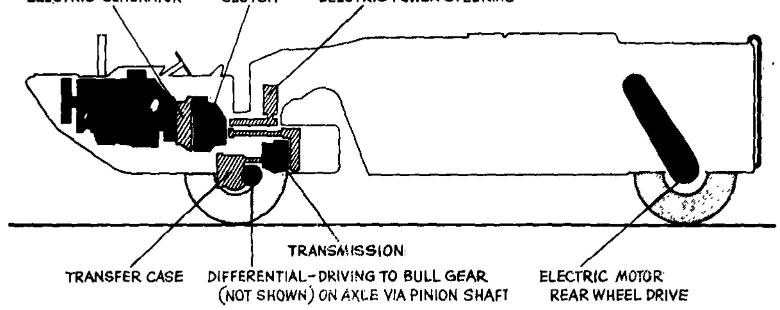
From R. G. LeTourneau, Inc. Reprint of Industrial Design, Nov. 1958

EXHIBIT I

LeTOURNEAU-WESTINGHOUSE MODEL #90 HAULPAK

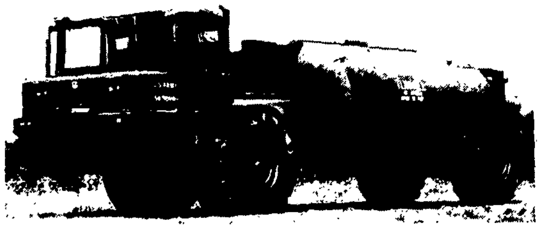
EXHIBIT J

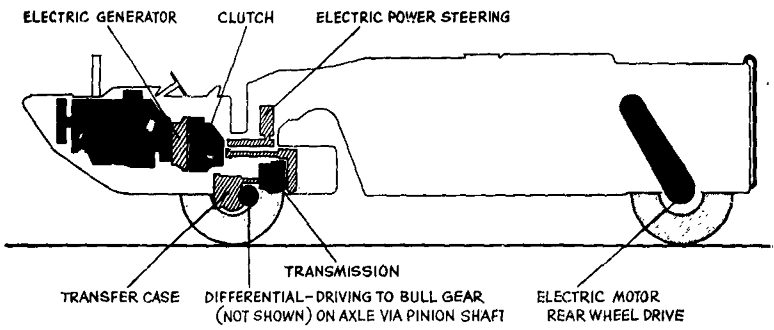
LeTOURNEAU-WESTINGHOUSE "GOER"



Drive train and arrangement of major mechanical components. This is schematic only since profile of actual vehicle has a shorter nose overhang and engine is beside rather than ahead of operator.

GOER high-mobility cargo truck (below), designed and built by LeTourneau-Westinghouse for the U.S. Army, carries a payload of 15 tons. Another version (at right) is a 5000-gal tank truck.





Drive train and arrangement of major mechanical components. This is schematic only since profile of actual vehicle has a shorter nose overhang and engine is beside rather than ahead of operator.

GOER high-mobility cargo truck (below), designed and built by LeTourneau-Westinghouse for the U.S. Army, carries a payload of 15 tons. Another version (at right) is a 5000-gal tank truck.

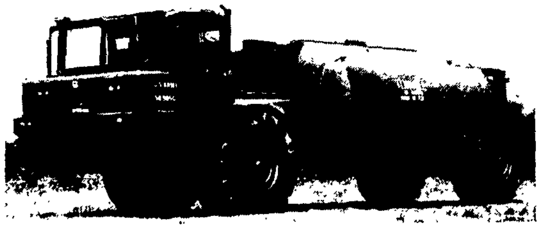


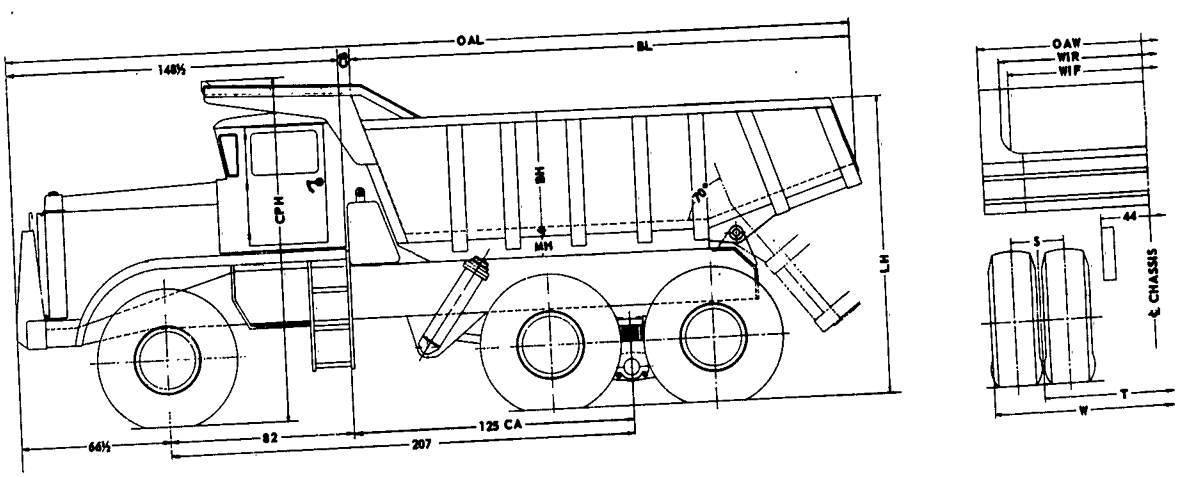
EXHIBIT K

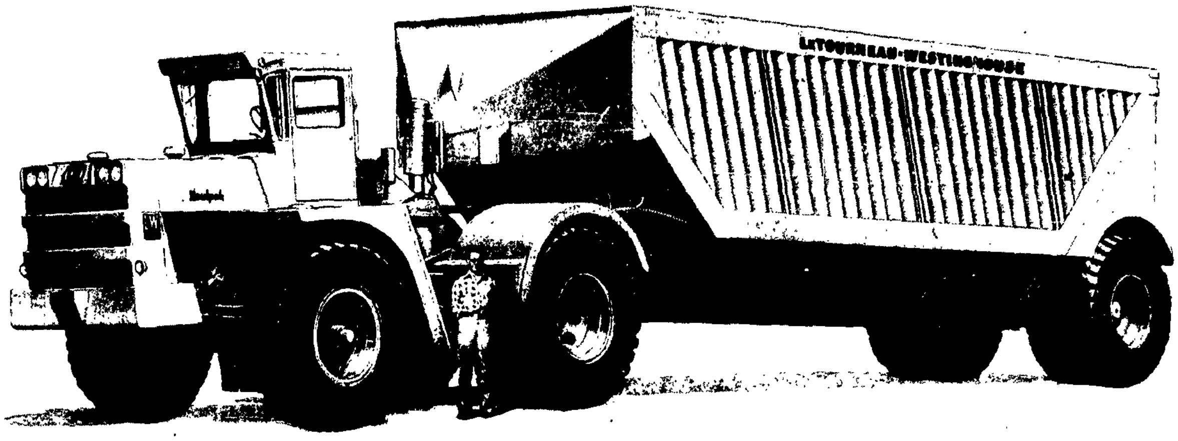
LeTOURNEAU-WESTINGHOUSE MODEL #60 HAULPAK

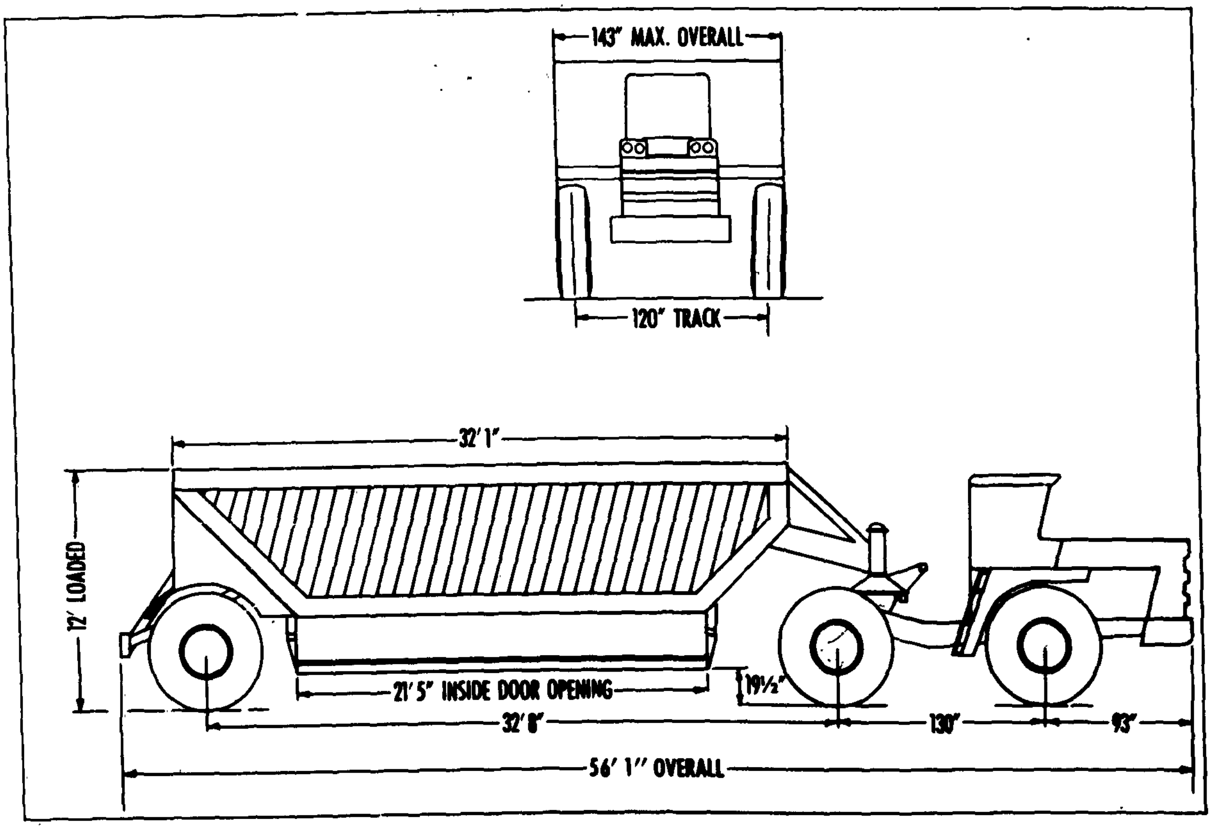
AND

AUTO CAR MODEL #AP-40


Autocar
Autocar


OAL
BL
148½
CPH
BH
MH
70°
LH
66½
82
207
125 CA
OAW
WIR
WIF
44
S
℄ CHASSIS
T
W


LeTOURNEAU-WESTINGHOUSE


143" MAX. OVERALL
120" TRACK
32' 1"
12' LOADED
21' 5" INSIDE DOOR OPENING
19½"
32' 8"
130"
93"
56' 1" OVERALL